

Preface

Game theory has recently been enjoying increased popularity in the research community, as it provides a new perspective on optimization, networking, and distributed control problems. It incorporates paradigms such as Nash equilibrium and incentive compatibility, it can help quantify individual preferences of decision-makers, and it has an inherently distributed nature. Consequently, game theoretic models have been applied to a variety of problem domains ranging from economics to computer science, networking, and security. Game theoretic models provide not only a basis for analysis but also for design of network protocols and decentralized control schemes. This makes it attractive as a theoretical framework for the design of networks and in particular communication networks. Applications range from power control in wireless communications to congestion control for the Internet, as well as sensor or ad-hoc networks.

As the backbone of the Internet, optical networks provide huge bandwidth and interconnect countries and continents. Unlike conventional networks, which are well-established and even standardized, the optical networks field is much younger, and in fact still evolving. Designing and setting up networking applications within the optical context is inherently more difficult than in conventional wired or wireless networks, in part due to the more complex physical-layer effects, and in part due to the lack of automatic methodologies developed for optical networks. But in these respects, the optical networking field has seen a tremendous growth in recent years.

From a game theory and control perspective, there are a multitude of problems to be tackled in the optical networks area and the field is still in its infancy. Aside from the fact that the area is much younger, research work requires an unusual blend of interdisciplinary expertise. In this spirit, the present monograph draws the author's research background in control theory, practical industrial experience in optical networks, and more than five years of research in game theory and control in optical communications.

The book is focused on mathematical models, methodologies, and game theory for optical networks from a control perspective. The general setup is that, given an optical communication network and some performance measures to be optimized among many networks units/players/channels, one must design an algorithm that

achieves as good a performance as possible for each channel. The algorithm should be decentralized and provably convergent, and should use localized and decentralized feedback. By regarding channels in the network as players in a game this multi-objective optimization problem fits within the setup of game theory.

The first theoretical question of interest is how to formulate meaningful and tractable game theoretical problems that can be used as a basis for developing such algorithms, taking into account the various mathematical characteristics arising naturally in optical networks. These mathematical characteristics are imposed by physical constraints and by network specific features and topologies. They translate into constraints on the game formulation (separable versus coupled action space), constraints on player's interaction (localized versus global interaction, i.e., one shot game versus stage or partitioned game), and constraints on players' actions (global constraints versus propagated/modified constraints).

Thus, one of the characteristics of optical networks is that game theoretic formulations and results cannot be transferred directly from other application domains (e.g., wireless networks or congestion control). Due to inherent physical complexities, the optical area uncovers new theoretical problems, such as games with coupled utilities and coupled constraints. Moreover, in the networking setup these constraints are modified across the network links and a framework for dealing with network games has to be developed. This makes game theory in optical networks an excellent starting point that could open new research problems and that could be generalized to other classes of games in networks.

This monograph has a two-fold aim. Its first goal is to provide researchers in the control and game theoretic community with background on the rich problems and the initial results in this area. There is a broad scope for fundamental control and game theoretical research; the hope is that the book will provide background material such that non-specialists in optical networks can approach these research problems within the optical networking domain. The book's second goal is to provide researchers in the networking and optical community with game theoretical methodologies that could be used to solve optical networking problems.

The following topics are covered. In the first part of the book, two chapters present non-cooperative game theory background and some new mathematical results for Nash equilibria computation in games with coupled constraints. In the second part, background and mathematical models for optical networks are presented, followed by game theory formulations developed for various topologies. The basic game considered is a power control game in the class of games with continuous action spaces, coupled utilities in normal form. The book in fact introduces in a systematic, gradual way the different types of game theoretical problems: first games with no coupled constraints in normal form, then games with coupled constraints; all-to-all interaction versus localized player interaction, which leads to games in ladder-nested form; multi-link (single-sink) and finally mesh topologies and how to deal with games in such scenarios, while building on the simpler cases and results. The third part considers issues such as robustness and time-delay effects, as well as other types of game problems in optical networks, including routing and path coloring games.

Much of the work in game theory applications has been within the framework of networking or computer science fields. Essentially, this book uses a mathematical approach developed from a control theoretical perspective. This is different from a networking approach, which is typically application-specific and focused on particular protocols, and unlike algorithmic-only approaches as typically used in computer science. Game theoretical problems are mathematically formulated herein in a systemic manner, with analytic conditions derived for existence and uniqueness of Nash equilibrium. Based on these, iterative algorithms with provable convergence properties to Nash equilibria are developed. The control theoretic approach to games as taken here allows for the treatment of important issues such as stability and time-delay effects in a dynamic system context. The abstract mathematical models and results could be applied to other application domains.

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